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Role of Scale Wettability on Rain-Harvesting Behavior in a Desert-Dwelling Rattlesnake

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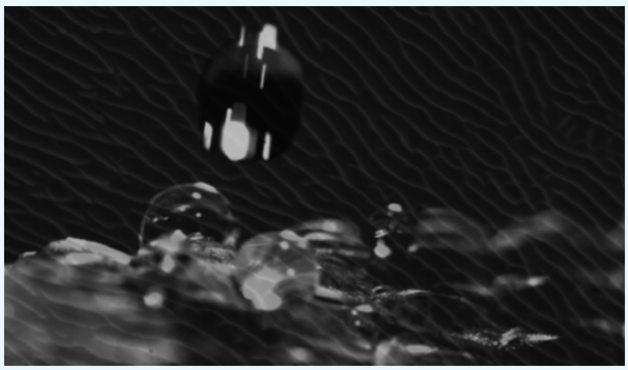
Supporting Information

ABSTRACT: During storms in the southwestern United States, several rattlesnake species have been observed drinking rain droplets collected on their dorsal scales. This process often includes coiling and flattening of the snake's body, presumably to enhance water collection. Here, we explored this rain-harvesting behavior of the Western Diamond-backed Rattlesnake (*Crotalus atrox*) from the perspective of surface science. Specifically, we compared surface wettability and texture, as well as droplet impact and evaporation dynamics on the rattlesnake epidermis with those of two unrelated (control) sympatric snake species (Desert Kingsnake, *Lampropeltis splendida*, and Sonoran Gopher Snake, *Pituophis catenifer*). These two control species are not known to show rain-harvesting behavior. Our results show that the dorsal scales of the rattlesnake aid in water collection by providing a highly sticky, hydrophobic surface, which pins the impacting water droplets. We show that this high pinning characteristic stems from surface nanotexture made of shallow, labyrinth-like channels.



INTRODUCTION

To survive in xeric environments such as desserts, many plants and animals have evolved specialized mechanisms and strategies for collecting water from atmospheric moisture, fog, or infrequent rains. Well-known examples include dew harvesting by New- and Old World desert lizards[1−3] and fog-droplet collection by several beetle species in the Namib Desert.[4−7] In several of these cases, the unique way in which water is harvested from the environment is enabled by highly specialized epidermal surface characteristics of the animal's body. In the case of desert lizards, their skin has hydrophilic microtexture that facilitates direct condensation, as well as contact collection of dew, rainfall, and absorption from moist sand, with subsequent capillary transport of water to the mouth.[8] Remarkably, the surface of the Namib desert beetle's wings has chemical and textural heterogeneities, which create hydrophilic−superhydrophobic pattern that enables the capture, coalescence, and rolling of fog droplets into the insect's mouth.[6]

Here, we discuss how a desert-dwelling rattlesnake uses its body to collect (harvest) and drink rain droplets and show how surface properties of its dorsal scales play a key role in that process. In the absence of a direct (freestanding) source of water, various species of rattlesnakes[9−11] that inhabit deserts have been reported to use their bodies to collect or harvest rain for drinking. Intriguingly, the Western Diamond-backed Rattlesnake (*Crotalus atrox*) from southern Arizona has been observed to emerge from rock-structured dens even during late winter to harvest rain, sleet, and snow.[9]

Regardless of the physical state of the collected water, these snakes are reported to flatten (dorsoventral flattening) their bodies considerably and at times form a tight coil (see images in Figure 1a) for rain harvesting, presumably to enhance the collection of rain droplets. As the rain droplets accumulate and coalesce on the dorsal scales (with diameters of up to about 5 mm), the snake proceeds to drink the water from various areas on its body. Notably, the process of liquid intake from the scales to the mouth does not differ from drinking from other types of sources or surfaces, including freestanding water.[12]

Other species of snakes have been reported to drink rain (or sprayed water) droplets from their bodies,[13−16] but rain harvesting by certain species of rattlesnakes stands out as a common and important behavior for survival in hot and xeric environments.[10] Rattlesnakes, like many other snakes, are known to have an elaborate nanotexture on their dorsal scales.[17] However, the potential role these textures have on the interaction with water during the phenomenon of rain harvesting has not been explored. Accordingly, we systematically characterized surface nano-to-macroscale texture and its effect on surface wettability and water droplet impact dynamics

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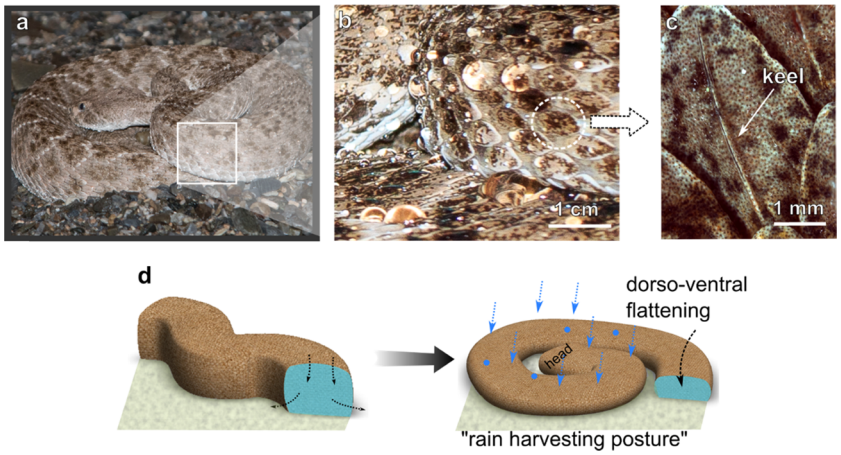

Figure 1. In situ rain harvesting of *C. atrox*: (a) image of the snake drinking rain droplets harvested on its coiled body, (b) close-up of the droplets clinging to the scales during water harvesting, (c) microscope image of a single dorsal scale of *C. atrox* with a highlighted central keel, (d) schematic of *C. atrox* illustrating the dorsoventrally flattened and coiled posture utilized for rain harvesting. The photographs in (a) and (b) are a courtesy of B. O'Connor.

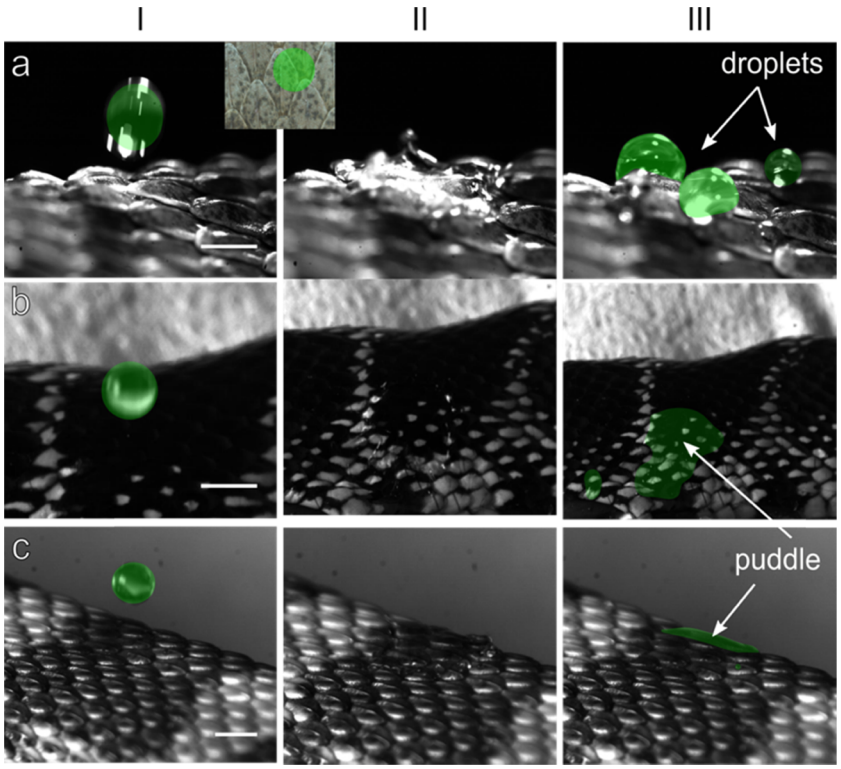

Figure 2. Image sequence (left to right) of the droplet impacting the snake's dorsal scales when released from a single height (12.5 cm) for the three samples: (a) *C. atrox* shows the droplet sticking to its scales after the impact (inset: geometrical scaling of the droplet with respect to scale), whereas (b) *L. splendida* and (c) *P. catenifer* shows the droplet spreading on the scales and forming a puddle while also losing the water due to shedding. The scale bar corresponds to 2.5 mm.

on the dorsal skin (scales) of adult Western Diamond-backed Rattlesnakes (*C. atrox*), a New World viperid (Viperidae: Crotalinae). Two snake species (family Colubridae) that are syntopic with *C. atrox* in the Sonoran Desert were also studied for comparison, the Desert Kingsnake (*Lampropeltis splendida*) and Sonoran Gopher Snake (*Pituophis catenifer*). The latter two snake species are not known to show rain-harvesting behavior. The Desert Kingsnake (*L. splendida*) has macroscopically smooth dorsal scales, while the Sonoran Gopher Snake (*P. catenifer*) and *C. atrox* have macroscopic (observable) keels running through the center and entire length of each dorsal scale of the main body (see Figure 1c). By performing water droplet impact and evaporation experiments on the dorsal scales of these three snake species, we demonstrate that the nanotexture and wettability of rattlesnake skin, but not the controls, aid in rain droplet capture for drinking.

■ RESULTS AND DISCUSSION

An example of in situ rain harvesting of *C. atrox* is illustrated in Figure 1a, where the image shows the coiled posture of the snake. In this posture, the snake also flattens its body

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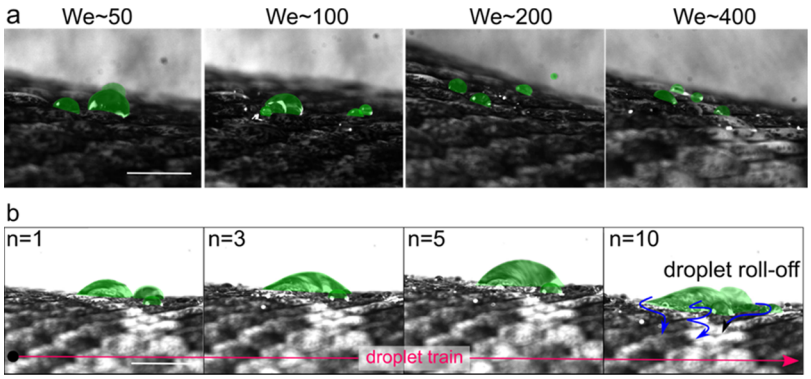

Figure 3. Images from a high-speed recording of the droplet impacting the scales of *C. atrox*, (a) single droplet delivered with increasing Weber number (*We*) achieved by changing the droplet release height from 12.5 to 120 cm, (b) image sequence showing the droplet agglomeration on dorsal scales of *C. atrox* when subjected to repeated contact with impacting droplets (*n* stands for the number of droplets). After 10 droplets, the agglomerate becomes large enough and rolls off. The scale bar corresponds to 5 mm.

(dorsoventral flattening) to maximize the area for droplet collection (Figure 1d). The close-up image (Figure 1b) reveals numerous rain droplets of various sizes and moderate contact angles on the dorsal scales. The moderate contact angles imply a mildly hydrophilic to hydrophobic surface. It is important to note that droplets of a range of sizes collected on scales even on the lateral regions of the body do not roll off but adhere to the scales. In addition to the individual droplets, puddles as deep as 5 mm in size accumulate on the dorsal scales for brief periods owing to droplet coalescence. Subsequently, these droplets and puddles are consumed (imbibed) by the snake, which moves only its head and anterior-most body to avoid disturbing the collected water on the scales and drinks the droplets. Based on these in situ qualitative observations, the scales of *C. atrox* appear to facilitate water-harvesting behavior by offering a "sticky" surface that promotes droplet adhesion. To provide quantitative insight into this process, we perform controlled droplet impact experiments on dorsal scales of the three snake species.

Droplet Impact Tests. In the first test, we delivered a single drop of water (~10 μL) on the snake sample from a fixed 12.5 cm height. Figure 2 shows the sequence of three images indicating different times of the droplet impact: I—before, II—during, and III—after the impact. The procedure was repeated multiple times for all three samples. A comparison between images in column III shows different outcomes of the droplet impact on the three samples. For both the kingsnake and the gopher snake (see Figure 2b,c), we see that the impacting droplet either forms a shallow puddle or slips off the body depending upon the area of contact (top vs side). In contrast, *C. atrox* splits the impacting droplet into a couple of secondary droplets, which get pinned to the scales (see Movie 1). Consequently, the single-droplet impact experiments on the three snake species show a strong correlation between highly pinning epidermis and the rain-harvesting behavior.

To provide a further understanding of droplet−surface interactions during rain-harvesting behavior, we expanded droplet impact experiments only on *C. atrox* with droplet release heights increased up to 120 cm. In the lowest height (12.5 cm), impact velocities of the drops were very low ~1 m s^{-1}, which could be representative of scenarios such as water dripping from rocks and bushes, which have been observed in the field.[9,10] In the highest release height (120 cm), the terminal velocity of droplets is approximately 4−5 m s^{-1}, which represents a light-to-medium stratiform rain.[18] If we compare these scenarios in terms of the Weber number of the impacting droplet, which represents the ratio of inertia to surface tension forces (product of density, diameter, and the square of the droplet's velocity divided by its surface tension), the experiments span from 40 to 400. As this number increases, the inertia force dominates over surface tension forces. Consequently, the primary droplets break down into more secondary droplets upon a higher impact. Many of these droplets adhere to the scales, while a portion bounces off the scale. However, even in such cases, we observed that numerous secondary droplets are pinned to the scales (see Figure 2c-III), which can also be seen in Figure 1b. Thus, even at high droplet Weber numbers, the scales can help retain much of the impacting water, albeit less effectively than at lower Weber numbers. Also, it should be noted that samples used in these experiments were deceased; so, the dorsoventral flattening, as well as coiling, could not be reproduced during the tests. Since this flattening and coiling behavior is likely to significantly impact the amount of retained water, we did not attempt to quantify its relation to the Weber number.

Harvesting water from rain directly or indirectly involves repeated contact with droplets. Thus far, we considered only the single-droplet impact, which does not fully represent the natural scenarios. To simulate more realistic conditions, we deposited multiple droplets from the height of 30 cm on dorsal scales at regular intervals. The image sequence in Figure 3b shows results from these experiments. After the first droplet impacts and splits into a few pinned droplets, the subsequent incoming droplets cause them to coalesce forming an agglomerated pool. This coalescence continues until the size of the puddle is sufficiently large, which then slides off the body. Even with higher Weber numbers (see Figure 3a, ~400), the numerous smaller droplets act like "collection sites" for subsequent droplets and collect the water over longer durations as can be seen in Figure 1b.

Nano-to-Macroscle Characterization of the Dorsal Scales. Independent of the impact scenario, our droplet experiments show that scales of *C. atrox* aid in retaining the water droplets, which helps in the rain-harvesting behavior. Our wetting measurements indicated that the dorsal scales of *C. atrox* have a significantly higher contact angle than those of the *L. splendida* and *P. catenifer*. In particular, on the dorsal scales of *C. atrox*, we measured a highly hydrophobic effective water contact angle of 118 ± 12°. In turn, the dorsal scales of

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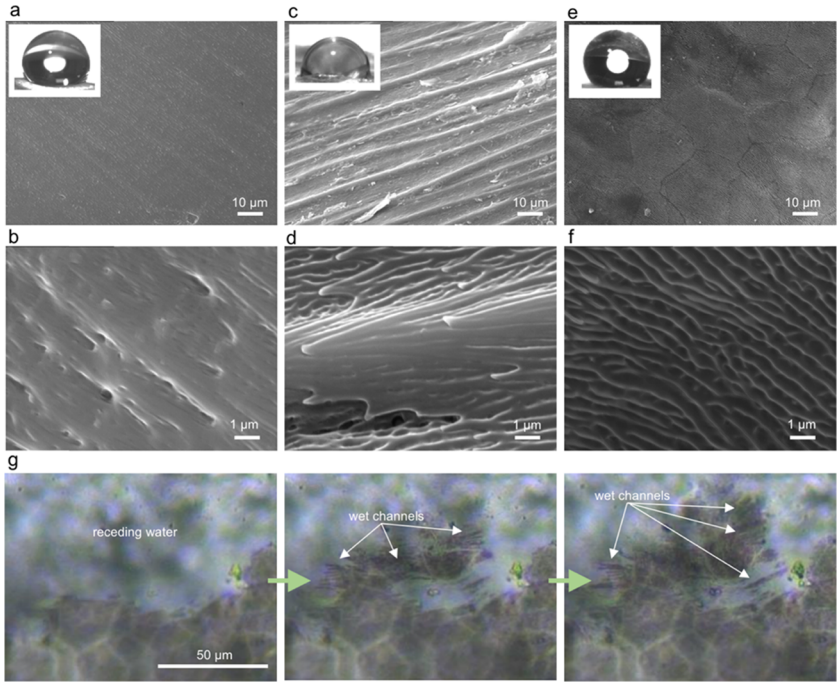

Figure 4. SEM images of scales of (a, b) *L. splendida*, (c, d) *P. catenifer*, and (e, f) *C. atrox*; insets show representative images of the water droplet on the corresponding scales; (g) sequence of light microscopy images showing the edge of a drying droplet on the scales of the *C. atrox*.

the *L. splendida* were significantly less hydrophobic with an effective water contact angle of 104 ± 8°, while those of the *P. catenifer* were, on average, mildly hydrophilic with an effective water contact angle of 88 ± 11°.

The differences that we observed in the wettability of the snake scales likely stem from some variability in the intrinsic wetting properties of the scale material, as well as their surface texture.[19,20] The scales of all of the snakes consist of β keratin along with some lipids.[21] The intrinsic wettability of these materials is not well characterized but is known to vary depending on their composition from mildly hydrophilic to mildly hydrophobic.[21,22] Since the roughening of a surface magnifies its wetting properties, the relatively significant difference in the observed contact angles, especially between the *C. atrox* and *P. catenifer*, likely stems from the moderate difference in inherent wetting properties of the scales' material that are amplified by the underlying surface texture.

On nano- to microscale, the surface topology of the dorsal scales of the snakes can range from nearly smooth to highly complex.[17] Specifically, the scanning electron microscope (SEM) images of the scales of *L. splendida* (Figure 4a,b) reveal a nearly smooth surface without any discernible nanopattern. The scales of *P. catenifer* have a more distinct nanoscale pattern of parallel, shallow, and 5−10 μm long nanochannels, whose consecutive layers appear to stack on each other (Figure 4c,d). In addition, the scales of *P. catenifer* have microridges with a height of a few micrometers that are spaced 10−20 μm apart and run along the scale. The parallel, shallow nanochannels occur predominantly in between the microridges whose tops, by comparison, are much more smooth. In turn, the scales of *C. atrox* (Figure 4e,f) have only nanochannels that are separated by prominent nanoridges that run almost parallel to each other over a shorter scale (of the order of a few micrometers) and make a complex, labyrinth-like network of closely packed channels at a larger scale. These narrow ridges of approximately 100 nm width and 300 nm height are spaced by, on average, around a 600 nm gap. The labyrinth-like patterns are segregated by thin, mostly straight, boundaries into four- to five-sided regions that measure 30−50 μm across. The boundaries of these regions are also easily observed under an optical microscope, as shown in Figure 4g.

Imaging of the receding triple-phase contact line (TPCL) during the evaporation of a droplet shows that water penetrates into nanochannels and is pinned by the nanoridges on the *C. atrox* scales. Specifically, the sequence of optical images in Figure 4g shows the formation of multiple parallel water lines within the large-scale regions as the droplet evaporates. The fact that the TPCL does not recede smoothly but breaks up into multiple areas dictated by the surface nanoridges provides another illustration of the highly pinning nature of the *C. atrox* scales (see also Movie 3). In contrast, the TPCL during droplet evaporation on the scales of *P. catenifer* is continuous and occurs predominantly along the microridges (see Movie 4 and Supporting Information). Consequently, water penetrates into the topological features on both the scales of *C. atrox* and *P. catenifer* (i.e., droplets are in Wenzel state; see the Supporting Information for additional experimental demonstration). This is not surprising since drop meniscus can penetrate several hundred nanometers into a gap between two nanostructures with such a spacing.[23,24] Interestingly, a natural example showing that deeper channels are required to induce a nonwetting Cassie−Baxter state was recently discovered on scales of the West African Gaboon Viper (*Bitis rhinoceros*). These scales have a comparable but considerably deeper nanotexture and, as a result, are superhydrophobic (contact angle of about 160° and negligible contact angle hysteresis).[21]

In light of the wetting and topographical characterization, as well as the droplet evaporation experiments, the difference in the droplet impact dynamics of the *C. atrox* and *P. catenifer* scales stems predominantly from the moderate difference in their effective wetting properties, as well as from the highly pinning nature of the dense nanoridge labyrinth on *C. atrox*

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scales. These topological features increase the adhesion of both the primary and the secondary droplets, which enables the accumulation of a substantial amount of water on the back of the *C. atrox*.

Finally, with regard to the macroscale structure of the scales of *C. atrox*, the prominent keel at the center along its length is speculated to serve several purposes, such as in camouflage.[25] From the work we report, the keel might complement the nanostructure by splitting a droplet and reduce the Weber number. For example, in our droplet impact experiments, we observed that a droplet is more likely to split about the keel and disintegrate into smaller droplets. It is well established that such a macrotexture can split impinging water droplets, redistributing the mass of the droplet and therefore significantly reducing the total contact time between the liquid and the surface.[26−28] While the dorsal scales of gopher snake also have a keel, it is far less prominent and did not induce any particular interactions with the droplets. Thus, apart from potentially helping to split some of the impacting droplets, the keel on the scales of *C. atrox* appears at this time unlikely to have a major role in water collection. Nonetheless, the role of the keel on dorsal scales will require further investigation in *C. atrox* and other species that possess them.

■ CONCLUSIONS

In summary, we explored the role of the dorsal-scale surface characteristics on the rain-harvesting behavior of the Western Diamond-backed Rattlesnake (*C. atrox*). Specifically, we compared wettability, surface texture, and droplet impact dynamics on the rattlesnake epidermis with those of two unrelated (control) sympatric snake species (Desert Kingsnake, *L. splendida*, and Sonoran Gopher Snake, *P. catenifer*). These two control species are not known to show rain-harvesting behavior. Our results show that the scales of *C. atrox* exhibit the highest contact angle and have a dense labyrinth-like nanotexture. When interacting with water, this shallow nanotexture strongly pins the triple-phase contact line. Using a set of droplet impact tests, we show that the textured scales are effective in collecting droplets in different rain-harvesting scenarios reported for this species. Consequently, it is the nanoscale-scale characteristics that allow the snake to collect the water droplets on its body for consumption during infrequent rains in arid climates such as deserts and maintaining a hydrated state.

■ EXPERIMENTAL SECTION

Samples. In this study, we used fresh (minutes-old) road kills as well as shed skins of the three species of snakes as our samples: Western Diamond-backed Rattlesnake (*C. atrox*; Family Viperidae) and two colubrids (Family Colubridae), the Desert Kingsnake (*L. splendida*) and Sonoran Gopher Snake (*P. catenifer*). The samples were collected on Portal Road in Cochise County, Arizona, during the spring of 2019. Post collection, they were stored in plastic bags and placed on ice in an insulating container for 6−24 h duration before being tested. In addition, shed skins of captive snakes were also analyzed for reference. We did not observe any difference in texture or wetting dynamics between the two types of snakeskin samples. To the best of our knowledge, rain-harvesting behavior reported for *C. atrox* has not been reported for the other two species we studied, and thus we use them as our control samples. Information on body mass, snout-vent, and tail lengths for the three samples we report here is provided in Table 1.

Table 1. Physical Details of the Snake Samples

sample	snout-vent length, mm	tail length, mm	body mass, g
C. atrox	813	64	349
L. splendida	635	95	110
P. catenifer	965	152	461

Droplet Experiments. We built a droplet impact setup to deliver water droplets of approximately 10 μL volume (diameter ∼2.5 mm). The flow rate of water was controlled using a syringe pump (NE-2000, New Era Pump Systems). The height of the delivery head consisting of a syringe tip is kept adjustable to change the Weber number of the impacting droplets (from a height of 12.5−120 cm). The samples were placed in such a way that the droplets were mostly landed on dorsal scales. All high-speed imaging was done using a FASTCAM mini ux100 and Nikon D5200 digital SLR camera. A few portable banks of light-emitting diode (LED) lights were used for lighting purposes.

For the droplet evaporation experiments, about 0.5−1 μL droplets were spread over the shed skin samples of *C. atrox* and *P. catenifer*. The droplets were allowed to naturally evaporate into the laboratory environment with a temperature of around 18 °C and a relative humidity of 10−20%. From qualitative observation, the droplets evaporated in a constant base area mode until the contact angle decreased substantially and the contact line was easily accessible using an optical microscope (Zeiss Axio Zoom V16 with a 10× lens). The use of the translucent shed skin samples enabled through-sample illumination, which strongly facilitated imaging. The images were recorded with a 2 Hz frequency.

To test for the possibility of heterogeneities in wetting properties of the scales, we also performed simulated fog collection experiments. Specifically, as in our previous work,[29] we directed outflow from an ultrasonic water fog generator, which is a component of an Electro-tech Systems controlled humidity chamber, over the samples that were placed under the optical microscope. In contrast to the distinct heterogeneities observed during such experiments on some beetle species,[4−7] we did not observe any preferential collection sites.

Contact Angle Measurements. The contact angles of deionized water on the dorsal scales of the three species were measured using a Rame-hart 290 goniometer with 15−20 locations studied (30−40 contact angle measurements) per each sample. The indicated uncertainty corresponds to a standard deviation of the measurements. Since we did not measure any difference between the scales on the above-described specimen and the collected shed skins, we performed the more extensive contact angle measurements using the shed skin samples. To remove extensive surrounding topological features, the shed skin samples were cut into about 3−5 mm wide and 2 cm long strips and attached to a glass slide using double-sided copper tape. The resulting images were analyzed using ImageJ. Please note that although the ventral scales of the snakes appear macroscopically smooth, and thus potentially better sites for contact angle measurements than the dorsal scales, there are significant differences in microscopic topological features between these two body locations (see the Supporting Information). Consequently, we only

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measured contact angles on the dorsal scales, which are relevant to the rain-harvesting behavior.

Sample Imaging. The optical microscopy was done using an Axio Zoom V16 (Zeiss) attached with a 10× lens. The SEM images of the scale surface morphology were obtained using an Amray 1910 FESEM. Either shed or freshly dehydrated scale samples were sputter-coated with a thin conductive metal layer prior to imaging. The images were postprocessed in ImageJ for analysis.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsomega.9b02557.

Imaging of TPCL during droplet evaporation from *P. catenifer* scale, additional imaging of water droplets on *C. atrox* scales, comparison of topography of dorsal and ventral scales of *C. atrox*, and schematic of the droplet impact setup are supplied (PDF)

C. atrox splits the impacting droplet into a couple of secondary droplets, which get pinned to the scales (MOV)

Droplet impact experiments on *C. atrox* with increasing droplet release heights (MOV)

Illustration of the highly pinning nature of the *C. atrox* scales (MOV)

TPCL during droplet evaporation on the scales of *P. catenifer* is continuous and occurs predominantly along the microridges (MOV)

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) Bentley, P. J.; Blumer, W. F. C. Uptake of Water by the Lizard, Moloch Horridus. *Nature* **1962**, *194*, 699−700.

(2) Sherbrooke, W. C. Rain-Harvesting in the Lizard, Phrynosoma Cornutum: Behavior and Integumental Morphology. *J. Herpetol.* **1990**, *24*, 302−308.

(3) Joel, A.-C.; Buchberger, G.; Comanns, P. Moisture-Harvesting Reptiles: A Review. In *Funcional. Surfaces in Bioliology III*, 1st ed.;Borb, S. N., Gorb, E. V., Eds.; Springer Nature: Cham, Switzerland, 2018; pp 93−106.

(4) Parker, A. R.; Lawrence, C. R. Water Capture by a Desert Beetle. *Nature* **2001**, *414*, 33−34.

(5) Nørgaard, T.; Dacke, M. Fog-Basking Behaviour and Water Collection Efficiency in Namib Desert Darkling Beetles. *Front. Zool.* **2010**, *7*, 23.

(6) Zhai, L.; Berg, M. C.; Cebeci, F. C.; Kim, Y.; Milwid, J. M.; Rubner, M. F.; Cohen, R. E. Patterned Superhydrophobic Surfaces: Toward a Synthetic Mimic of the Namib Desert Beetle. *Nano Lett.* **2006**, *6*, 1213−1217.

(7) Chakrabarti, U.; Paoli, R.; Chatterjee, S.; Megaridis, C. M. Importance of Body Stance in Fog Droplet Collection by the Namib Desert Beetle. *Biomimetics* **2019**, *4*, 59.

(8) Comanns, P.; Withers, P. C.; Esser, F. J.; Baumgartner, W. Cutaneous Water Collection by a Moisture-Harvesting Lizard, the Thorny Devil (Moloch Horridus). *J. Exp. Biol.* **2016**, *219*, 3473−3479.

(9) Repp, R. A.; Schuett, G. W. Western Diamond-Backed Rattlesnakes, *Crotalus atrox* (Serpentes: Viperidae), Gain Water by Harvesting and Drinking Rain, Sleet, and Snow. *Southwest. Nat.* **2008**, *53*, 108−114.

(10) Aird, S. D.; Aird, M. E. Rain-Collecting Behavior in a Great Basin Rattlesnake (*Crotalus viridis lutosus*). *Bull. Chicago Herpetol. Soc.* **1990**, *25*, 217−218.

(11) Glaudas, X. Rain-Harvesting by the Southwestern Speckled Rattlesnake (*Crotalus michellii pyrrhus*). *Southwest. Nat.* **2009**, *54*, 518−521.

(12) Cundall, D. Drinking in Snakes: Kinematic Cycling and Water Transport. *J. Exp. Biol.* **2000**, *203*, 2171−2185.

(13) Greene, H. W. Natural History and Evolutionary Biology. In *Predator-prey Relationships: Perspectives Approaches from Study Lower Vertebrates*, 1st ed.; Feder, M. E., Lauder, G. V., Eds.; University of Chicago Press: Chicago, 1986; pp 99−108.

(14) Robinson, M. D.; Hughes, D. A. Observations on the Natural History of Peringuey's Adder, *Bitis peringueyi* (Boulenger)(Reptilia: Viperidae). *Annls. Transv. Mus.* **1978**, *31*, 189−193.

(15) Louw, G. N. *The Role of Advective Fog in the Water Economy of Certain Namib Desert Animals*, Symposia of the Zoological Society of London, 1972; Vol. 31, pp 297−314.

(16) Abe, A.; Andrade, D. V. Water Collection by the Body in a Viperid Snake, *Bothrops Moojeni*. *Amphibia-Reptilia* **2000**, *21*, 485−492.

(17) Arrigo, M. I.; Vilaca, L. M. D. O.; Fofonjka, A.; Srikanthan, A. N.; Debry, A.; Milinkovitch, M. C. Phylogenetic Mapping of Scale Nanostructure Diversity in Snakes. *BMC Evol. Biol.* **2019**, *19*, No. 91.

(18) Pruppacher, H. R.; Klett, J. D. Microstructure of Atmospheric Clouds and Precipitation. In *Microphysics of Clouds and Precipitation*; Springer Netherlands: Dordrecht, 2010; pp 10−73.

(19) Xia, F.; Jiang, L. Bio-Inspired, Smart, Multiscale Interfacial Materials. *Adv. Mater.* **2008**, *20*, 2842−2858.

(20) Liu, M.; Zheng, Y.; Zhai, J.; Jiang, L. Bioinspired Super-Antiwetting Interfaces with Special Liquid-Solid Adhesion. *Acc. Chem. Res.* **2010**, *43*, 368−377.

(21) Spinner, M.; Gorb, S. N.; Balmert, A.; Bleckmann, H.; Westhoff, G. Non-Contaminating Camouflage: Multifunctional Skin Microornamentation in the West African Gaboon Viper (*Bitis rhinoceros*). *PLoS One* **2014**, *9*, No. e91087.

(22) Badge, I.; Stark, A. Y.; Paoloni, E. L.; Niewiarowski, P. H.; Dhinojwala, A. The Role of Surface Chemistry in Adhesion and Wetting of Gecko Toe Pads. *Sci. Rep.* **2014**, *4*, No. 6643.

(23) Rykaczewski, K.; Landin, T.; Walker, M. L.; Scott, J. H. J.; Varanasi, K. K. Direct Imaging of Complex Nano- to Microscale Interfaces Involving Solid, Liquid, and Gas Phases. *ACS Nano* **2012**, *6*, 9326−9334.

(24) Jones, P. R.; Hao, X.; Cruz-Chu, E. R.; Rykaczewski, K.; Nandy, K.; Schutzius, T. M.; Varanasi, K. K.; Megaridis, C. M.; Walther, J. H.; Koumoutsakos, P.; Espinosa, H. D.; Patankar, N. A. Sustaining Dry Surfaces under Water. *Sci. Rep.* **2015**, *5*, No. 12311.

(25) Mallow, D.; Ludwig, D.; Nilson, G. *True Vipers: Natural History and Toxinology of Old World Vipers*; Mallow, D., Ludwig, D., Nilson, G., Eds.; Krieger Publishing Company: Malabar, 2003.

(26) Bird, J. C.; Dhiman, R.; Kwon, H.-M.; Varanasi, K. K. Reducing the Contact Time of a Bouncing Drop. *Nature* **2013**, *503*, 385−388.

DOI: 10.1021/acsomega.9b02557
ACS Omega 2019, 4, 21141−21147

(27) Gauthier, A.; Symon, S.; Clanet, C.; Quere, D. Water Impacting on Superhydrophobic Macrotextures. *Nat. Commun.* **2015**, *6*, No. 8001.
(28) Liu, Y.; Andrew, M.; Li, J.; Yeomans, J. M.; Wang, Z. Symmetry-Breaking in Drop Bouncing on Curved Surfaces. *Nat. Commun.* **2015**, *6*, No. 10034.
(29) Damle, V. G. V. G.; Linder, R.; Sun, X.; Kemme, N.; Majure, L. C.; Rykaczewski, K. Why Is It Difficult to Wash Aphids off from Superhydrophobic Kale? *Bioinspiration Biomimetics* **2016**, *11*, No. 054001.

DOI: 10.1021/acsomega.9b02557
ACS Omega 2019, 4, 21141−21147